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Using ocean robots on high-resolution profiling to capture the fast-flowing Agulhas Current

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The Argo programme was developed to provide near real-time observations of the ocean and contribute significantly to understanding the changes occurring in ocean temperature and salinity in the upper 2000 m. Riser et al.[1] showed that, for profiles sampling both temperature and salinity to 1000 m or deeper, the Argo programme produced, in just under 16 years, three times as many profiles as all other shipboard observations in the past 100 years. Furthermore, Argo observations have occurred globally, albeit with higher resolution in regions where deployment opportunities were more prevalent.

But what happens in particularly turbulent or fast-flowing current regions such as Western Boundary Currents (WBC) and mesoscale eddies? Errors are reported to be high when Argo data are used to plot monthly and seasonal evolution of structures within turbulent WBCs as a result of the lack of spatial resolution of Argo data.[1] In an attempt to improve observations, the Argo Steering Team has suggested additional float resources be assigned to fast-flowing WBC regions.[1] While this addition may be sufficient for regions where deployment opportunities are numerous, in areas such as the Agulhas Current or the Mozambique Channel, where far fewer research cruises are conducted, another option is to set Argo floats to collect data at higher resolutions.

The Agulhas Current propagates along the east coast of South Africa at peak surface speeds of 1.8 m/s (~155 km/day),[2] and is the fastest WBC of the southern hemisphere. The Agulhas Current is considered stable from Durban in the north to Port Alfred in the south (Figure 1), a distance of ~570 km. Furthermore it is unique in that mesoscale eddies contribute to its source from east of Madagascar and the Mozambique Channel, and mesoscale eddies and Agulhas Rings are shed at the Agulhas Current termination as it retroflects back on itself into the Indian Ocean.[3] The Agulhas Current is not accurately resolved in climate models and thus forecasts used for the International Panel for Climate Change and similar misrepresent this feature, which is largely responsible for the transport of heat and salt from the Indian to Atlantic Oceans.[4] Improved resolution in-situ measurements of this WBC and its source regions are thus crucial for an accurate assessment of the contribution of the Agulhas Current and its sources to the transport of heat and salt.

Mesoscale eddies in the Mozambique Channel, originating usually in the narrows to the north of the Channel, extend to the full depth of the water column as found in in-situ measurements.[5,6] Eddies originating from the South-East Madagascar Current form in dipole pairs, around four to six per year[7], with a strong jet found between the two lobes of the dipole propagating southwestwards[7,8]. Halo et al.[9] showed that mesoscale eddies are indeed highly non-linear and capable of transporting material, such as biological organisms, between Madagascar and the African continent. But to what depths does this transport capability extend with particular emphasis on heat and salt input from the Indian Ocean interior into the Agulhas Current, especially given the significant decrease in velocities below 500 m in the limited in-situ data already available? In order to quantify this extent, dedicated research cruises undertaking extensive CTD (conductivity, temperature and depth) surveys across mesoscale eddies would be required –

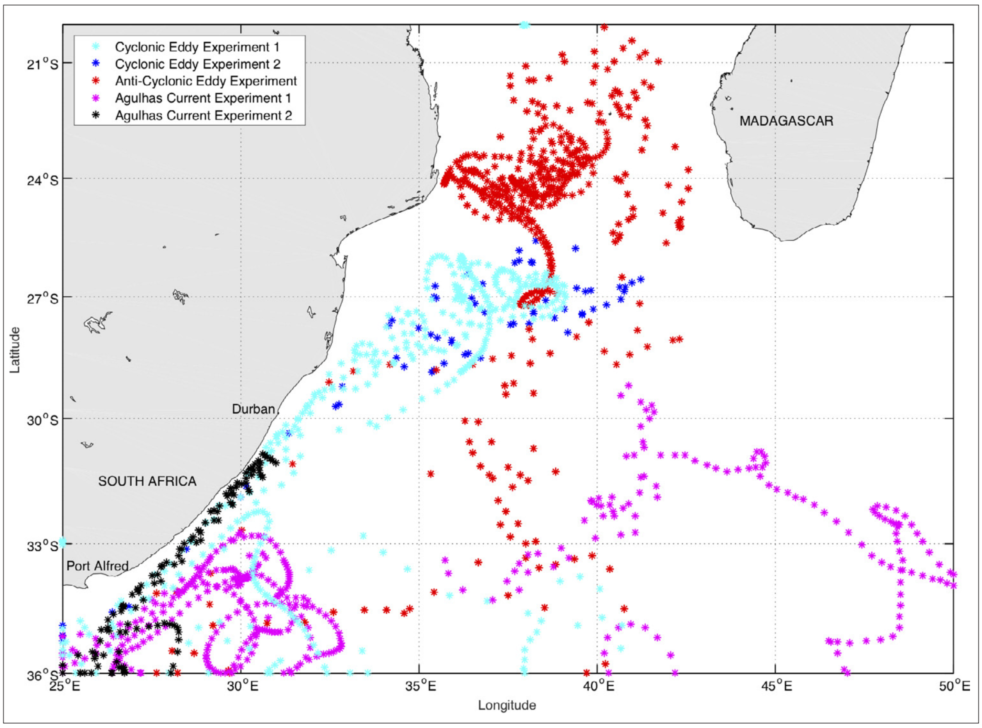

Figure 1: Five high-resolution Argo profile experiments conducted between 2013 to 2017 in the source regions of and the Agulhas Current itself.

an incredibly expensive undertaking. A more affordable solution would be to deploy Argo floats profiling at higher resolution than that of the standard 10-day mission. Understanding what is being contributed to the Agulhas Current from its turbulent sources is imperative in order to validate coupled-climate models for better forecasting capabilities, to accurately assess physical dynamics impacting the coastal regions and critically track the transport of heat and salt, as well as pollutants such as microplastics.

Historically, scientific research cruises have been concentrated on the west and south coasts of South Africa because of the rich fisheries in these regions, whereas the east coast has had limited exposure to long-term studies of its powerful current. Intermittently deployed mooring arrays have been used to acquire data from the Agulhas Current[2,4,10], and opportunistic surveys along the coast have been used to glean additional information whenever possible[11,12]. In contrast, much of the understanding of the northern hemisphere WBCs comes from Argo float data and, when it is possible to deploy fairly regularly, a detailed picture can emerge.[1] For the Agulhas Current, this paucity in in-situ data is further exacerbated by its relatively short length (~ 570 km) and with peak surface speeds of ~155 km/day, an Argo float on the standard profiling of 10 days could miss the Agulhas Current completely in its propagation along the east coast.

With support of Argo teams from the USA, UK and Europe, South African researchers have begun using Argo floats with higher profiling frequencies[13], daily or five-daily as opposed to the standard 10-daily profiling mission, to understand this dynamic WBC and the influence of mesoscale eddies from its source regions, as well as the fate of heat and salt transported by these features. The park and profile depths of these Argo floats were set to be shallower than the standard mission to ensure the floats were maintained within the features. Over the last 5 years, five experiments have been conducted on mesoscale eddies in the southern Mozambique Channel, and along the Agulhas Current (Figure 1). For the entire duration (2000 to 2017) of the Argo programme to date, 136 floats propagated along the east coast of South Africa have acquired 276 profiles within the Agulhas Current (Figure 2). For the 18 floats set to higher sampling frequencies for the five experiments, 199 profiles were collected (Figure 2) – a number more than two thirds higher than that achieved by standard mission floats in close to 17 years, thus dramatically increasing the number of observations in this WBC. For the southern Mozambique Channel, the increase in the number of observations is less obvious (Figure 3a and 3b) given that

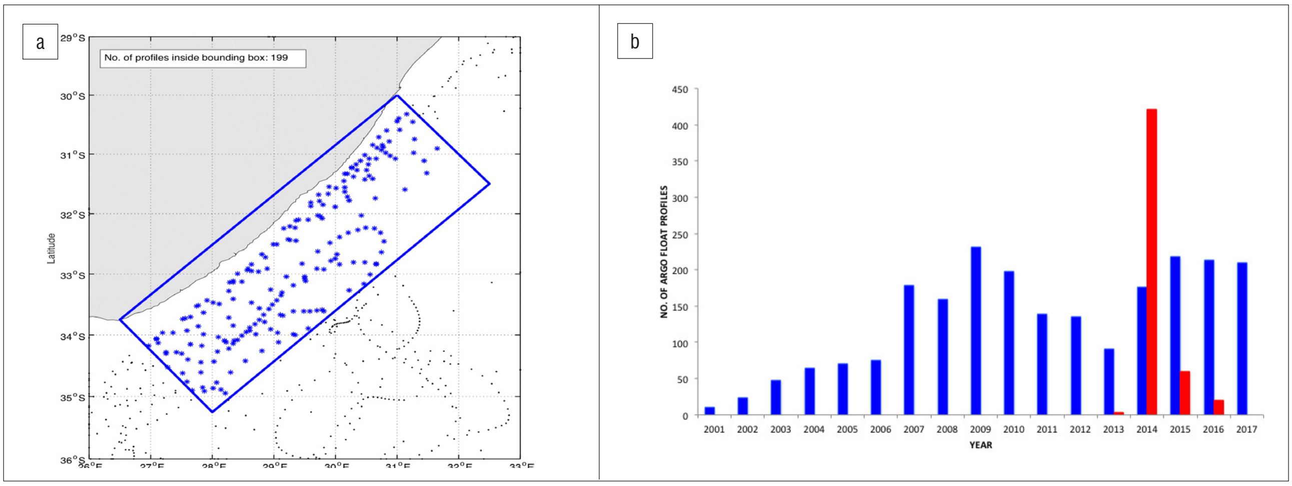

Figure 2: (a) Map of the east coast of South Africa for the 18 high-resolution floats used in the mesoscale eddy and Agulhas Current experiments, with the Agulhas Current region depicted (as per Beal et al.[2]) as a blue rectangle. (b) Histogram depicting, within the Agulhas Current bounding box, the profiles from standard profiling Argo floats (blue) and high-resolution Argo floats (red) per year.

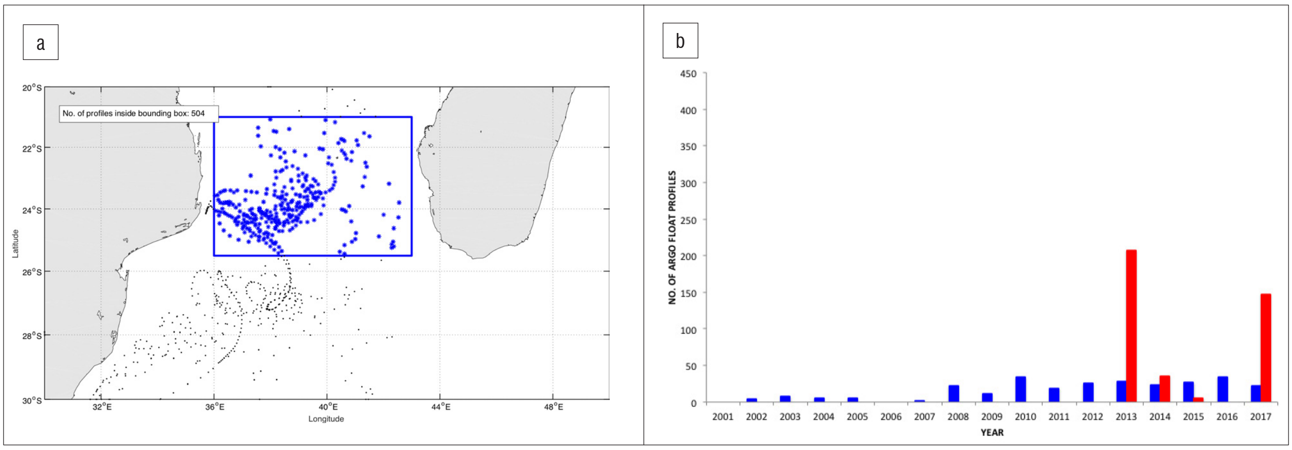

Figure 3: (a) Map of the southern Mozambique Channel for the nine high-resolution floats used in the mesoscale eddy experiments, with the southern Mozambique Channel region depicted as a blue rectangle. (b) Histogram depicting, within the Mozambique Channel bounding box, the profiles from standard profiling Argo floats (blue) and high-resolution Argo floats (red) per year.

fewer high-resolution deployments were undertaken in this region. What is important to note is that, although there are more profiles per year on standard float missions in the southern Mozambique Channel, these floats are not profiling down the Agulhas Current as successfully (Figure 2b), and are thus not capturing the change in dynamics from a turbulent region into the WBC.

With limited opportunities for dedicated research cruises in the Mozambique Channel to collect high-resolution CTD data, multidisciplinary cruises – such as that investigating a young cyclonic eddy spawned off southwest Madagascar in July 2013[14,15] – are crucial to further our understanding of these features. While it was possible to sample only a single high-resolution transect during the cruise[14,15], the deployment of Argo floats with higher profiling frequencies within that same eddy allowed for continuous sampling of water masses, heat, salt and volume transport of the eddy over a period of 4 months as the eddy moved from southwest Madagascar to the Agulhas Current off South Africa (Morris, unpublished data).

Arguably, high-resolution profiling is skewed to time periods when floats are deployed in these turbulent regions (Figures 2b and 3b); however detailed process studies have been made possible[16] and these results will extend our understanding of the role of mesoscale eddies in the upstream dynamics of the Agulhas Current, and the structure and dynamics of the Agulhas Current itself. With the advances in satellite technology, it is now possible to reprogram the float so that once it leaves the high-resolution study region it can be set back to standard Argo profiling, thus extending the battery life of the float. Increased data profiling will increase data transmission costs and put additional strain on Argo data centres to validate data, but these advances should be considered similar to those of Deep-Argo, biogeochemical sensors on Argo floats and the increased float deployments in the equatorial regions. Argo floats were never designed to answer all the physical dynamics questions about the ocean, but given the massive cost of research vessels and dedicated in-situ sampling, obtaining detailed information on particularly turbulent regions to fill in at least some of the gaps should be undertaken in whatever way possible.

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